Chapter

The Potential of Biomass in Africa and the Debate on Its Carbon Neutrality

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Abstract

To enhance the energy security and promote energy diversity, biomass sources of energy are viable resources worldwide. Bioenergy is an organic source of power derived from various feedstock including fuel wood, energy crops, solid wastes, and residues of plants. This book chapter explores the use of biomass in Africa and the technical and economic potential of these resources for energy supply in the continent. Findings of literature revealed that the potential of biomass is high in Africa due to availability of land, its preference due to limited electricity supply and the exorbitant nature of fossil fuels, the assorted variety of energy crops suitable for growth in the continent and the green nature associated with the resource. The chapter also established that bioenergy is renewable and not carbon neutral. As such, accurate computation of its resultant greenhouse gas emissions based on their sequestration and emission rates is strongly advised to optimize biomass for energy utility and sustainability compared to conventional energy sources.

Keywords: Africa, biomass, carbon emissions, environmental sustainability

1. Introduction

The global population is growing at a fast rate so that today's population is 200% more compared to the 1960s and is further projected to rise up to 9 billion by 2050 [1]. According to Jackson et al. [2], the global per capita energy use was rated to increase by 0.2% annually with consumption in developing countries such as India and China having an increased consumption rate of 3.4 and 1.6% per year, respectively. The European Union and USA recorded declined energy consumption rates of 0.3 and 0.2% per annum, respectively [2]. The increment trend has and is expected to increase the global energy demand particularly in urban areas of developing nations considering that these countries will account for 99% of the population growth and 50% of these individuals will be in major cities [3]. Energy increments are also attributed to industrial revolution and the need to realize the sustainable development goal number 17 on affordable and clean energy according to [4]. These anticipations though reasonable are against the current global efforts to mitigate climate change, which is a serious environmental crisis.

In response to these developments on accommodating accessibility of sufficient energy and mitigation of climate change effects, the global energy mix especially in urban areas is growing although many cities still rely heavily on conventional energy sources based on fossil fuels. The use of the energy sources has stirred a heated debate on energy sustainability since they are associated with environmental pollution and the apparent climate change state [1]. In China for instance, the exponential growth in use of natural gas resulted to a 2–7% increase in carbon dioxide emissions correspondent to extensive air pollution in China [2]. Evidence showing that cities are the greatest environmental polluters and climate change contributors from the 70% carbon dioxide emissions out of the total possible, most of which is anthropogenic-based confirms the need for alternative, reliable, easily accessible and low-carbon emitting energy sources [5]. Zaharia et al. [4] agreed with these sentiments claiming that prosperity, population and non-renewable energy consumption in developing economies of Asia and Africa are attributable to the rise in pollutant emissions.

Of these proposed alternatives in the energy mix is biomass, which is organic matter that is used as energy directly for heating and combustion or indirectly as biofuels [6]. Biofuel examples include wood shavings, sawdust, firewood, fruit stones (avocados, olives and nutshells) wastewater, manure, paper waste and pellets. Biomass especially from wood is a promising domestic energy source according to Bildirici and Ozaksoy [7] who reported that 81% of African population depend on it for economic, household and cooking activities. The wide availability of biomass obtained from agricultural and industrial processes' by-products justifies it high preference. Additionally, its direct and indirect uses to produce energy make its suitable in developing regions of Africa. However, it is worth noting that direct use of biomass is not always feasible and in some cases require additional treatment (biologically or physically) to prevent the effects of conventional fuels [1]. This book chapter focuses on the various sources of biomass in Africa and assesses their potential in addition to having a candid discussion on the carbon neutrality of biomass. Three categories of biomass including forestry biomass, energy crops and wastes or residues will be discussed. The prospects of the chapter will help in drawing a roadmap to providing reliable energy for socio-economic growth in Africa while at the same time, taking precautionary measures to conserve the environment.

2. Types of biomass

Biomass, which is sourced from organic matter from the biosphere (animal or plant origin) and through transformation of wastes, is a promising source of energy. This renewable energy source can be classified into three: (1) forestry biomass, (2) energy crops and (3) biomass from wastes and residues. These three forms of biomass will be discussed in the following sections.

2.1 Forestry biomass and residues

Forests as terrestrial ecosystems store and generate biomass, which justifies their applicability as energy sources since time immemorial [8, 9]. This biomass form differs based on topography, stand structure, site and management systems. Irrespective of the variations, forest is a primordial energy source due to its uniformity and availability globally as well its carbon neutrality [10, 11]. Forest biomass is removed as harvests or in silvicultural activities. Forest biomass is classified into two categories: (1) energy plantations and (2) timber systems where energy is produced as forest residues. Energy plantations are distinguished from agricultural crops from the ability to enhance their biodiversity, their variability globally, harvest flexibility, economic variability, low risk and their capacity to perform phytoremediation [12, 13]. Some countries such as China, Canada, USA and Europe have some of these plantations as documented by Goncalves et al. [14] and compared to developing countries. A number of factors such as the management practices, harvest cycle, rotation, density and the selection of species are considered in the growth of energy crops [14]. Forest residues include stumps, stems, limbs and tops of trees and their production depends on tree species, stem quality and stand structure [8].

The current share of forest biomass use is limited despite the known advantages of its use in energy production including the ability to convert it to transportation fuels, heat and electricity. The use of bioenergy and renewable wastes for energy supply accounted for 9.4% compared to all sources in 2015 [15]. Among these biomass supplies, 63.7% was from solid biofuels such as renewable municipal waste, biogas and liquid biofuels while other renewable biomass took the remaining share. Wood, wood fuel and wood residues produce heat and electricity and can be used indirectly by power plants combined with heat and power or directly by end users. Forest biomass contributed to 87% of biomass feedstock while 3 and 10% was from municipal waste and agricultural feedstock, respectively [16]. Examples of forest biomass sources include wood pellets, pine wood chips, pine bark, beech woos, willow wood, poplar and eucalyptus wood [17]. In sub-Saharan Africa, woody biomass is the main source of energy at domestic level and 81% of the population use it for economic, household and cooking activities [7]. This rate is by far higher compared to higher income developing countries of India and China. Although projections by the IEA as noted by Stecker et al. [18] claimed that wood biomass use for energy would reduce globally by 2035, it is noted that in Africa, this form of biomass will contribute to 51–57% of energy consumption. Wood biomass use in Africa varies with some countries such as Central African Republic, Burundi and Rwanda having a percentage use rate of 90% and above [18].

2.2 Energy crops

Energy crops are wild and cultivated crops, which produce biomass for various purposes. They exist as woody, herbaceous, perennial, or annual and generate raw materials for gaseous or liquid biofuels in addition to solid biomass. A number of factors including maintenance of land productivity, improved soil fertility, use of crop rotation systems, climate change adaptation and crop characteristics influence the successful production of energy crops [19]. Energy crops are used for three main purposes: 1) biodiesel, 2) bioethanol and 3) electric and thermal production [20]. Some of the crops used to produce biodiesel include *Cynara cardunculus,* cotton, *Glycine max, Helianthus annuus* and *Brassica napus*. Energy crops used in bioethanol production include *Beta vulgaris*, *Zea mays* and *Sorghum bicolor*, wheat among other cereals. *Miscanthus giganteus*, *Eucalyptus globulus* and *Arundo donax* are used in electric and thermal production. According to Lynd et al. [21], energy crops occur in four categories: (1) cellulosic such as trees, grass and a variety of wastes, (2) oil rich such as palm oil, soy, rapeseed and sunflower, (3) sugar rich including sugar beet and sugarcane and (4) starch rich crops such as sorghum, wheat and maize. A number of conversion technologies transform the crops to energy. These technologies include biological processes such as fermentation, lignocellulose hydrolysis and anaerobic digestion as well as non-biological processes such as transesterification, pyrolysis, gasification and combustion. African countries such as Kenya, Zimbabwe, South Africa, Tanzania, Ghana and Ethiopia have embraced the use of these biomass crops as energy sources in addition to the use of forest biomass, residues and other forms of wastes [21].

2.3 Biomass from wastes

Municipal solid waste commonly known as garbage comprises of leather and wood by-products, leaves, clippings from grass, food wastes, cardboard, paper and biogenic material from plants and animals. All these form biomass and can be transformed to energy for heating or steam for electricity generation. This has been done in developed countries such as the USA where in 2018, 14 billion kilowatt-hours of electricity from combusting 29.5 million tons of municipal solid waste was produced by 68 power plants [22]. More than 60% of the combustible waste consisted of biomass materials and accounted for the more than 50% of the generated power [22]. The remaining combustible weight was from non-biomass materials such as plastics. Landfill gas also made from biomass material is transformed to methane gas and used in energy production. In Africa, the use of municipal solid waste for energy production has high potential as Scarlat et al. [23] concluded in an evaluation of its potential especially in urban areas of the continent though it is done at small-scale levels.

3. An overview of biomass in Africa

Bioenergy from biomass is the primary source of energy for more than 2.7 billion people globally and serves a traditional role in Africa [24]. Organization for economic cooperation and development (OECD) [25] highlighted that more than 81% of the population accounting for 653 million Africans rely on biomass for their energy demands and the figure is expected to rise by 2030 to 720 million. The total energy demand in Africa is dominated by biomass that accounts for almost half (about 48%) of the total available sources (**Figure 1a**). A similar trend is evident in the sub-Saharan Africa as shown in **Figure 1b**. With the exclusion of South Africa, the rest of sub-Saharan Africa depends on biomass to a rate of more than

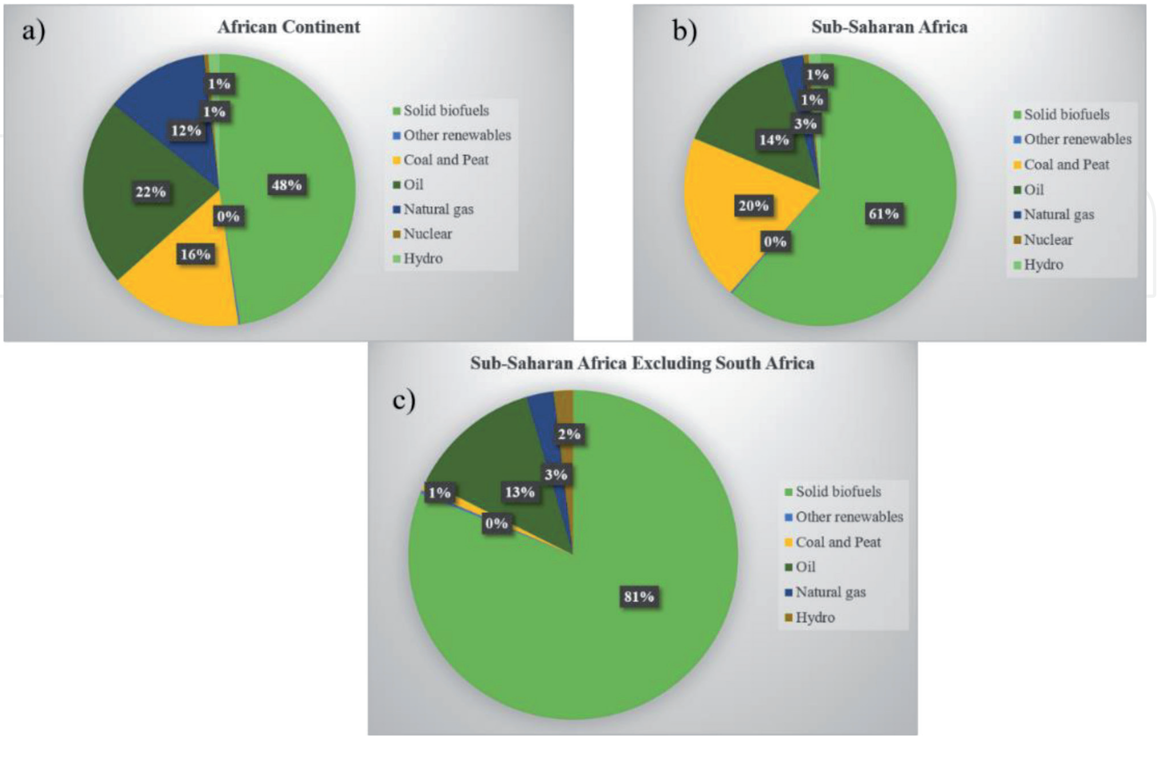

Figure 1.
Total biomass energy supply in (a) Africa, (b) sub-Saharan Africa and (c) sub-Saharan Africa excluding South Africa.

81%. (**Figure 1c**) Total biomass energy supply for the entire continent is at 28,177 petajoules (PJ) while in sub-Saharan Africa it is 21, 646 and 15,575 PJ including and excluding South Africa, respectively, according to the IEA data of 2009 [18, 26].

Apart from contributing to the primary energy demand in Africa, biomass also contributes significantly to the total final consumption. Although it is expected that this trend is on a reducing trend due to other competing uses of biomass such as animal feeds, organic sources and food, IEA [26] still projects that biomass sources will contribute to 51–57% of energy consumption by 2035 in the continent. In poorer countries of Africa especially those of sub-Saharan Africa excluding South Africa, the tendency to use biomass for energy is even higher according to Dasappa [27]. Usually the uses are traditional referring to the inappropriate use of animal dung, agricultural residues, animal dung, tree residues and fuel wood for space heating, lighting and cooking. This could be contrasted to modern biomass technical and effective use of energy characterized by high efficiency. Most of poor African population relies on traditional use of biomass for its energy uses despite the unsustainability of these trends, the rarity of quality biomass energy in these areas and the need for food security usually sourced from biomass sources [18]. The traditional uses of biomass via inefficient stoves is associated with indoor air pollution, soil degradation, forest degradation, ample time spent collecting firewood and ultimately, poverty [24]. These challenges necessitate a comprehensive analysis of biomass potential in Africa to find solutions towards having high quality, effective and efficient biomass. The following sections discuss the various biomass types with specific production levels in Africa and thereafter the potential of biomass in the continent.

Africa has more than 650 million hectares of forest cover, which accounts for 17% of the world's total area. The area covered is a fifth of the continent though the distribution of this resource is uneven with the Congo Basin and some areas of central and western Africa taking the largest share as shown in **Figure 2**. In the regions, production of wood products and round-wood is a key source of employment and African forests account for 0.85 ha per capita of population according to Dasappa [27]. Approximately 1% of the continent is characterized as forest plantation while the tropical rain forests account to 25% of such areas globally. Due to the lack of recent statistics, this study used the Food and Agriculture Organization [29] data to show the forest product statistics for some African countries as shown in **Table 1**. Summarizes the wooded and forested areas of Africa with statistics showing 645 Mha accounting for 21% of total area as having biomass cover. Regions of central, west, east and South Africa have larger forested and wooded regions compared to the north. This could be because the latter has a considerable share of fossil fuel resources compared to other African regions.

Round-wood is the major forest product at 237 million tons compared to charcoal, fuel wood and industrial products at 15, 52, and 207 million tons, respectively. The ratio of wood fuel to round-wood for some named African countries ranges from 0.9 to 1. In addition to wood, the processing of wood generates residues such as tops, lops, sawdust and cut-offs that are used as biomass. During forest and plant production, residues in the form of leaves, husks, cobs, shells and stalks are produced and serve as useful biomass too.

In the use of municipal solid waste biomass in Africa for energy, the section is largely unexploited according to Hafner et al. [30]. This trend is predominant in the continent despite the great potential of valorizing waste biomass to generate renewable and efficient energy in addition to dealing with the current waste disposal crises if conducted in large scale. The UN Environment Program [31] lauds Ethiopia for constructing a waste biomass-to-power plant, which is one of the first in large-scale capacity in the continent. Africa has also taken up the use of energy

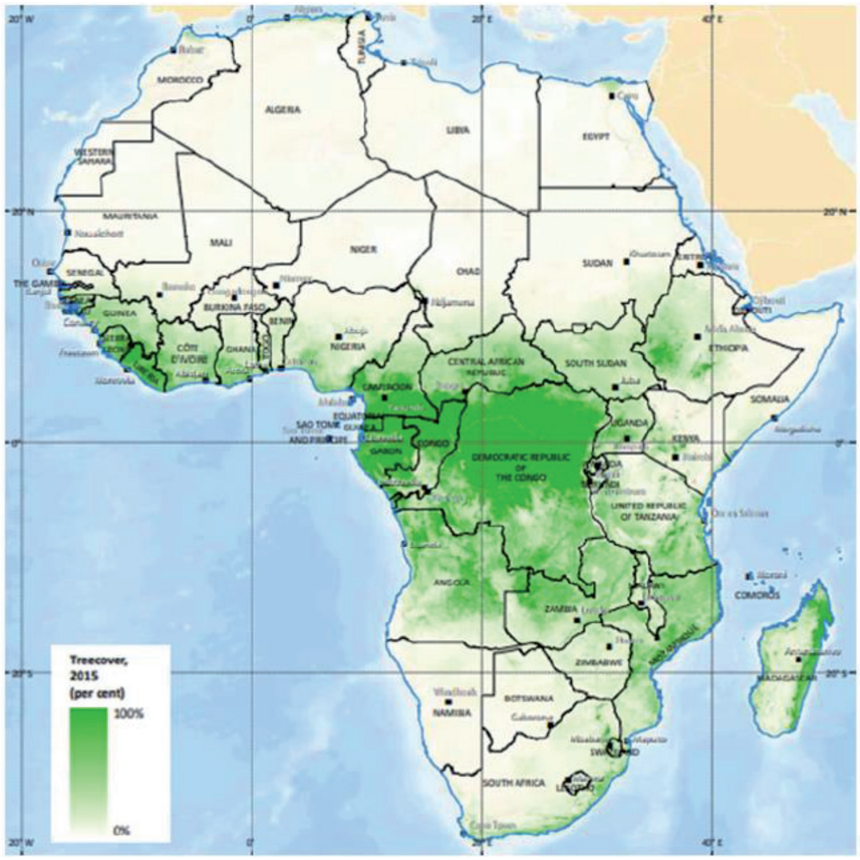

Figure 2.
Percentage of forest cover in Africa [28].

Region	Forested land area (1000 ha)	% Land area	Other wooded land (1000 ha)	Other land with tree cover (1000 ha)
Southern and Eastern Africa	226,534	27.8	167,023	10,345
Northern Africa	131,048	8.6	94,609	10,207
Central and Western Africa	277, 829	44.1	144,468	788
Total Area	645, 412	21.4	406,100	21,339

Table 1.
Forest and wooded areas in Africa according to the FAO 2005 statistics [27].

crops for biofuel production. The feedstock for such processes comes from: (1) first generation food crops such as cereals, sugarcane and vegetable oils, (2) from second generation crops such as wood, wastes and bagasse and (3) from third generation organisms such as algae. It is not easy to quantify the use of energy crops due in Africa due to their affiliated competition with food demands especially in famine prone areas of sub-Saharan Africa. Additional challenges including food-fuel competition exacerbated by corruption, weak governance, political instability and competition for land slow down efforts aimed at modernizing biomass for energy in most African countries [30]. IEA [32] expressed optimism that with the appropriate policies, African countries including Uganda, South Africa, Nigeria, Ghana and Mozambique could use biofuels to meet energy demands of their respective transport sectors. It is from this optimism that several examples of biomass use in Africa have been documented. These include bioethanol generation from sugarcane in Malawi, jatropha electrification in Mali, the use of sisal waste for biogas production in Tanzania and the production of ethanol from cassava in Benin [33–35]. In Zambia, Tanzania, South Africa, Sierra Leone, Liberia, Kenya, Ghana, Gambia, Cameroon, Burkina Faso and Botswana, policies on the use of bioenergy have been formalized and are in the implementation stages [36].

4. Potential of biomass in Africa

The potential of biomass in Africa has been examined in a number of studies especially in relation to available land [34, 35, 37]. These studies however focus on productive areas compared to arid and semi-arid regions. In Africa however, most of the area is largely arid of semi-arid characterized by mismanaged natural resources, low productivity and high vulnerability to climate change and soil erosion, which worsens the continent's poverty crises. The potential of biomass is therefore generalized using two aspects: (1) the availability of land and the viable production systems (technical potential) and (2) the expenditure and income resulting from biomass production (economic potential) that vary from humid to arid and semi-arid areas. Ultimately, with these considerations, the economic potential of bioenergy generation is affected. The next section focuses on Africa's biomass potential in relation to its technical and economic potential.

4.1 Technical potential

The technical potential of biomass is classified into two: (1) available land for bioenergy production and (2) viable biomass production systems. Available land defines the land left after current high biodiversity, agricultural and unsuitable areas are excluded. In this context, unsuitable areas include steep slopes, deserts and cities while high biodiversity areas include wetlands, forests, biodiversity hotspots and protected areas. In this context, Africa has a great technical potential of biomass as it has ample land for growth of bioenergy crops [27] and has serious electricity supply problems especially in rural areas steered up by poverty and

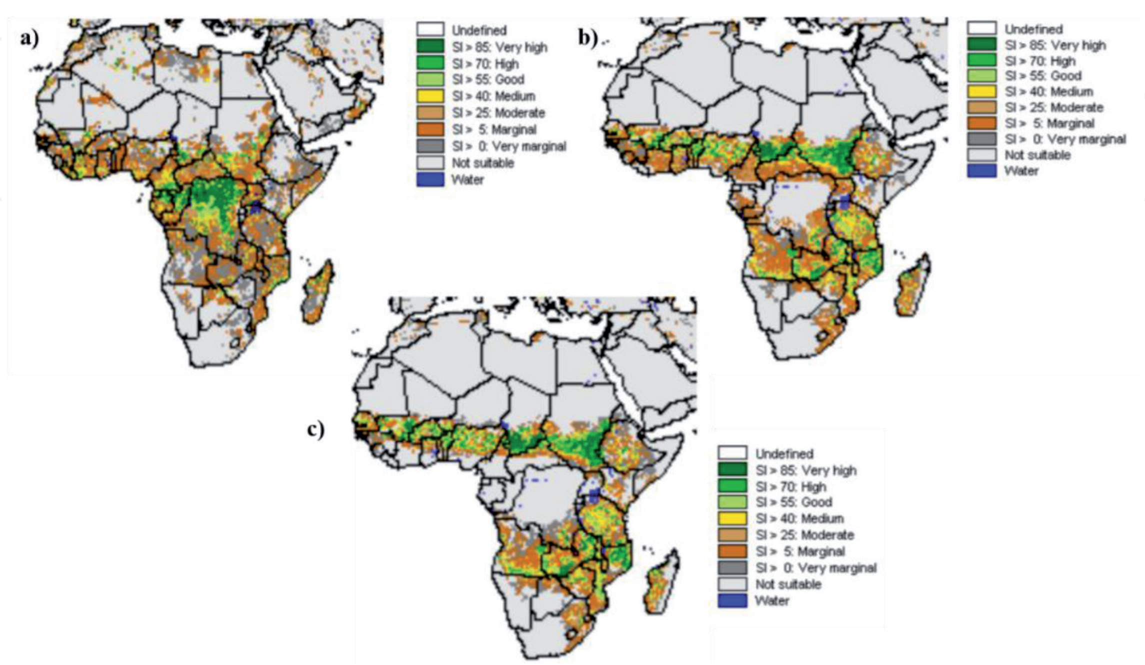

Figure 3.
The suitability of growing (a) sugarcane, (b) maize and (c) sorghum in Africa [40].

Bioenergy crop	Suitable conditions for optimal production	Yield for every hectare	Producing countries
Sugarcane	1600 meters (m) above sea level	4000 liters/ hectare (l/ha) in Africa	Mauritius, Zimbabwe, Swaziland, Kenya, Sudan, South Africa
Corn	Can grow everywhere with enough watering	700 l/ha in Africa	Tanzania, Kenya, Ethiopia, Nigeria, South Africa
Sweet sorghum	2500 m attitude in dry temperate and tropical areas	3000–6000 l/ha	Burkina Faso, Sudan, Ethiopia, Nigeria
Cassava	Above 1000 m attitude in tropical climate	1750 l/ha in Africa	Angola, Ghana, Mozambique, DR Congo, Nigeria
Palm oil	Above 700 m attitude in humid tropic climate	3000 l/ha in Africa	Ghna, DR Congo, Cote d'Ivoire, Nigeria
Jatropha	Above 500 m attitude and as low as 300 mm rainfall in semi-arid and tropical climate	40–2200 l/ha oil	Tanzania, Mozambique, Mali, Ghana

Table 2.
Some of the bioenergy crops grown in Africa, their climatic conditions, estimated yield rates and producing countries [38–39].

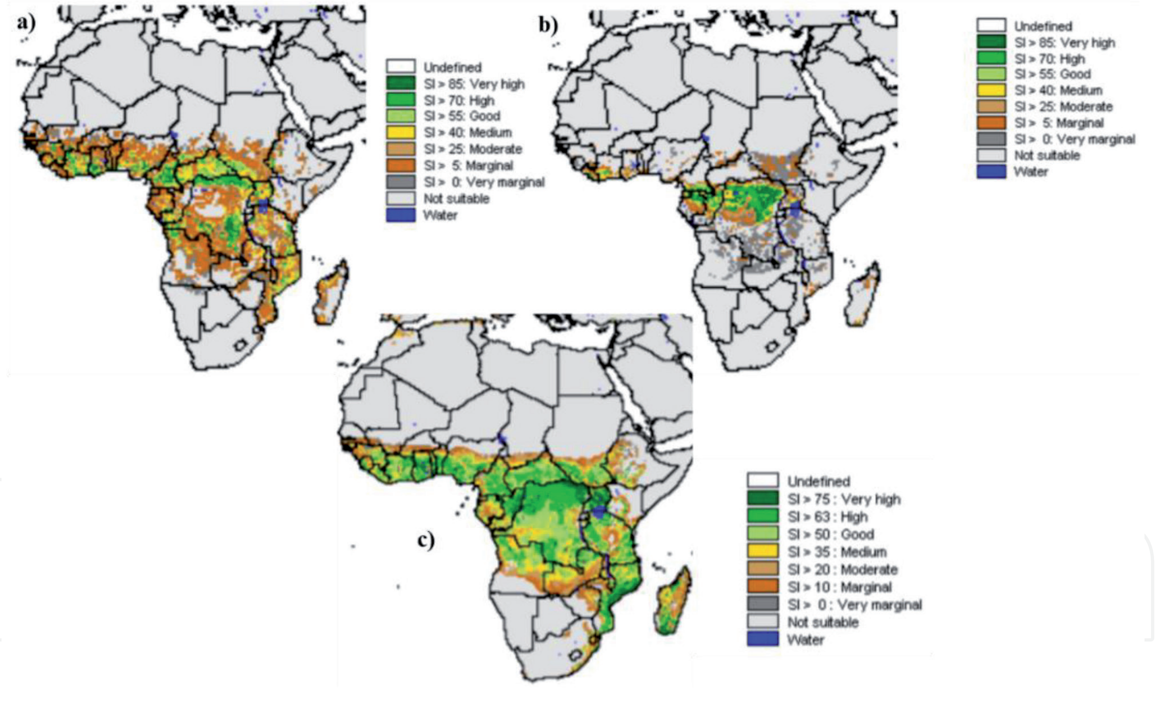

Figure 4.
The suitability of growing (a) cassava, (b) palm oil and (c) jatropha in Africa [40].

these factors could stimulate the use of biomass as an alternative energy source [30]. Kemausuor [38] supported the suggestion that Africa has high biomass potential by showing that its available land, harvested residues and bioenergy crops are higher compared to those of other parts of the world as shown in **Figure 3**. The figures on the available land by FAO also confirm the sufficiency of land for production of fuel wood and other bioenergy crops. However, the characteristics of African land such as its vulnerability to soil erosion, low productivity and misuse of natural resources coupled with traditional biomass uses are limiting factors to its optimal exploitation [24, 30]. Africa has many biofuel options from the many production systems of plants such as sugarcane, corn, sweet sorghum,

Country	Zambia	Tanzania	South Africa	Senegal	Mali	Kenya	Burkina Faso	Botswana
Transportation costs (US$$t^{-1}km^{-1}$)	0.07	0.07	0.05	0.08	0.08	0.07	0.08	0.05
Transport distance for cassava Arid areas (km)	-	-	636	40	92	35	164	121
Semi-arid areas (km)	36	35	69	57	37	26	40	39
Transport distance for fuelwood and jatropha Arid areas (km)	-	-	115	5	12	8	21	16
Semi-arid areas (km)	7	10	15	9	6	7	7	6
Land costs (US$ $ha^{-1}y^{-1}$)	20	20	93	22	22	20	22	93
Labour costs (US$ h^{-1})	0.3	0.3	4	0.4	0.4	0.3	0.4	1
Fertilizer costs for NPK (US$)	2102	2226	1521	2332	2332	1998	2332	2102
Yield rate of fuelwood Arid areas ($t\ ha^{-1}\ y^{-1}$)	-	-	1.1	5.7	2.7	8.9	6.3	0.7
Semi-arid areas ($t\ ha^{-1}\ y^{-1}$)	12.4	9.5	8.7	7.4	8.1	12.4	10	5.5
Yield rate of jatropha Arid areas ($t\ ha^{-1}\ y^{-1}$)	-	-	0.3	1.7	0.7	2	2.4	0.2
Semi-arid areas ($t\ ha^{-1}\ y^{-1}$)	2.7	2.5	2.3	2.7	2.6	2.4	3.1	2.5
Yield rate of cassava Arid areas ($t\ ha^{-1}\ y^{-1}$)	-	-	0.4	1.2	0.6	4.4	1.8	0.2
Semi-arid areas ($t\ ha^{-1}\ y^{-1}$)	4.9	8.9	4.8	2.8	3.4	7.5	3.8	2.3

Table 3.
The labour, land, transport and fertilizer costs of energy crops in some African countries in comparison to their yield rates [27].

cassava, palm oil and jatropha that are all energy crops [39]. The first three crops are collectively known as the ethanol crops while the last two are useful in biodiesel production. All the crops are economically and technically feasible in various parts of Africa based on their suitable conditions, yields from every hectare and some African producers summarized in **Table 2** [39].

Ethanol crops were initially developed for feed and crop production but their energy potential has suited the use of their biomass. Maize and sugarcane have greater potential since they are cultivated in many African countries at both small- and large-scale levels. Biodiesel crops include examples such as sunflower, castor oil, sesame, rapeseed, coconut, soya bean, jatropha and palm oil. However, for Africa palm oil and jatropha are focused on because of the high yield rates for every hectare and capacity to produce biofuel, respectively [39]. Areas where these energy crops are grown in Africa based on their suitability and according to the IIASA / FAI [40], statistics are shown in **Figures 3** and **4**.

4.2 Economic potential

Economic potential of biomass focuses on its production for profitable gains and with economic viability. To assess this biomass potential in Africa, costs of energy crop production such as inputs, labor, land and transportation costs from the farm until the last stage of energy conversions are considered. Other considerations according to Dasappa [27] include taxes, retail and wholesale margins, fertilizer and distribution costs. They help in comparing the economic viability of biomass energy with conventional energy prices. Some of these costs in eight named countries of Africa in comparison to the average yields of fuel wood, a biodiesel (jatropha) and ethanol (cassava) crop and according to literature are summarized in **Table 3** [27].

From the estimates of literature, the costs vary based on countries and there is need to adopt modern biomass uses that focus on efficiency and effectiveness even at the production levels [33, 34]. The costs in arid areas are higher compared to the semi-arid areas due to the challenges of land aforementioned in this chapter. The estimates are however, a simplification of the actual situation and more accurate and region specific estimates are needed as Dasappa [27] highlighted.

5. The carbon neutrality debate of biomass

Bioenergy or biomass energy has received a lot of attention globally as a viable alternative to conventional energy sources from fossil fuels because of its capacity to enhance energy security, result to economic growth and at the same time, cause minimal environmental impacts [41]. With this high attention drawn to biomass production and its subsequent conversion to bio power, researchers, government agencies, biomass feedstock generators and environmentalists are equally paying attention to its carbon neutrality issue. The carbon neutrality debate revolves around the ability of biomass production and conversion to energy processes resulting to zero increase in the greenhouse gas (GHG) levels in the atmosphere following a full life cycle basis. The debate influences future adoption to biomass sources and legislation on their use. During the contest, some bioenergy generators and biomass feedstock farmers support that associated energy resources are neutral since carbon released during biomass generation originates from feedstock that withdrew carbon from the atmosphere during growth. On the other hand, some environmentalists argue that bioenergy is not carbon neutral since the GHG emissions released in production of a unit of energy in a case such as combustion could even be higher than those of fossil fuels depending on the biomass type. Van Renssen [42] bases the debate on carbon neutrality of biomass energy sources to the inaccurate GHG emission assessment, which could result to long-term environmental issues.

To understand the debate around the carbon neutrality of biomass, this chapter does a summative focus on the carbon cycle. The cycle involves many pathways where carbon is exchanged between land, water and the atmosphere. Anthropogenic activities emit CO_2 and contribute to the carbon cycle. The contribution of CO_2 by humans is considerably small compared to other sources but once released to the environment; CO_2 is taken up by oceans, soils and vegetation at a slower rate compared to the emission rate [43]. Unless there are available CO_2 sinks in ocean and on land, the gas is likely to accumulate in the atmosphere causing modifications on the climatic conditions of the earth. Energy production is one of the human activities that releases significant amounts of CO_2. The net result of any energy production activity occurs in three ways: [43].

1. Carbon positivity, which defines activities that release CO_2 to the environment.

2. Carbon negativity, which defined activities that draw CO_2 more from the environment compared to the emission rates.

3. Carbon neutrality that defines activities leading to CO_2 absorption and release of equal measure.

To be carbon neutral, biomass has to meet the following four conditions according to Miner [44].

1. Compared to conventional energy sources, biomass sources should result to lower net increments of GHG emissions.

2. Emissions of biomass overall life cycle from the cultivation, harvesting and transportation processes should sum up to zero.

3. If biomass cultivation draws more atmospheric CO_2 compared to resultant emissions.

4. If by nature, biomass sources are carbon neutral then their products will be neutral too.

The suppositions by Miner [44] are contentious and escalate the carbon neutrality debate. For example, the assumption that biomass is carbon neutral naturally, fails to account for GHG emissions that occur during energy crop tendering processes such as fertilization. Additionally, the demand to remove CO_2 resulting from biomass growth equally means more planting of such crops. To assess the carbon neutrality of biomass compared to conventional fossil fuels, it is important to focus on their specific carbon cycles and identify differences as shown in **Figure 5**. Bioenergy has renewable sources of carbon in that plants can be re-grown and result to stable carbon concentrations compared to fossil fuel energy with finite sources of carbon that lead to additional CO_2 concentrations. Emissions from biofuels mainly occur from bio power technology type, feedstock production and transformation. This fact therefore suggests that the use of biomass as an alternative to conventional energy sources eliminates or reduces emissions from fossil fuels but also results to its own emissions and cannot possibly be carbon neutral as Bird et al. [45] suggested. The authors cited the example of combusting a metric ton of bone-dry wood that emits 1.8 tons of atmospheric CO_2. These differences coupled with the fact that feedstock growth consumes CO_2 could justify the ideologies of biomass as carbon neutral according to Bracmort [43].

A number of policies consider the burning of biomass as carbon neutral irrespective of their sources. Concurrently, the policies acknowledge the presence of carbon emissions using fossil fuels to process biomass but fail to narrow it down to CO_2 [45]. Through this error when computing emissions from bioenergy, they conclude that all biomass-based energy sources are carbon neutral. According to Haberl et al. [41] such policies are inaccurate. In another assumption, carbon neutrality is assumed since combustion of biomass releases the carbon that was initially drawn from the atmosphere as the plants were growing. This is a baseline error since the ideology fails to acknowledge that if energy crops were not harvested, they would

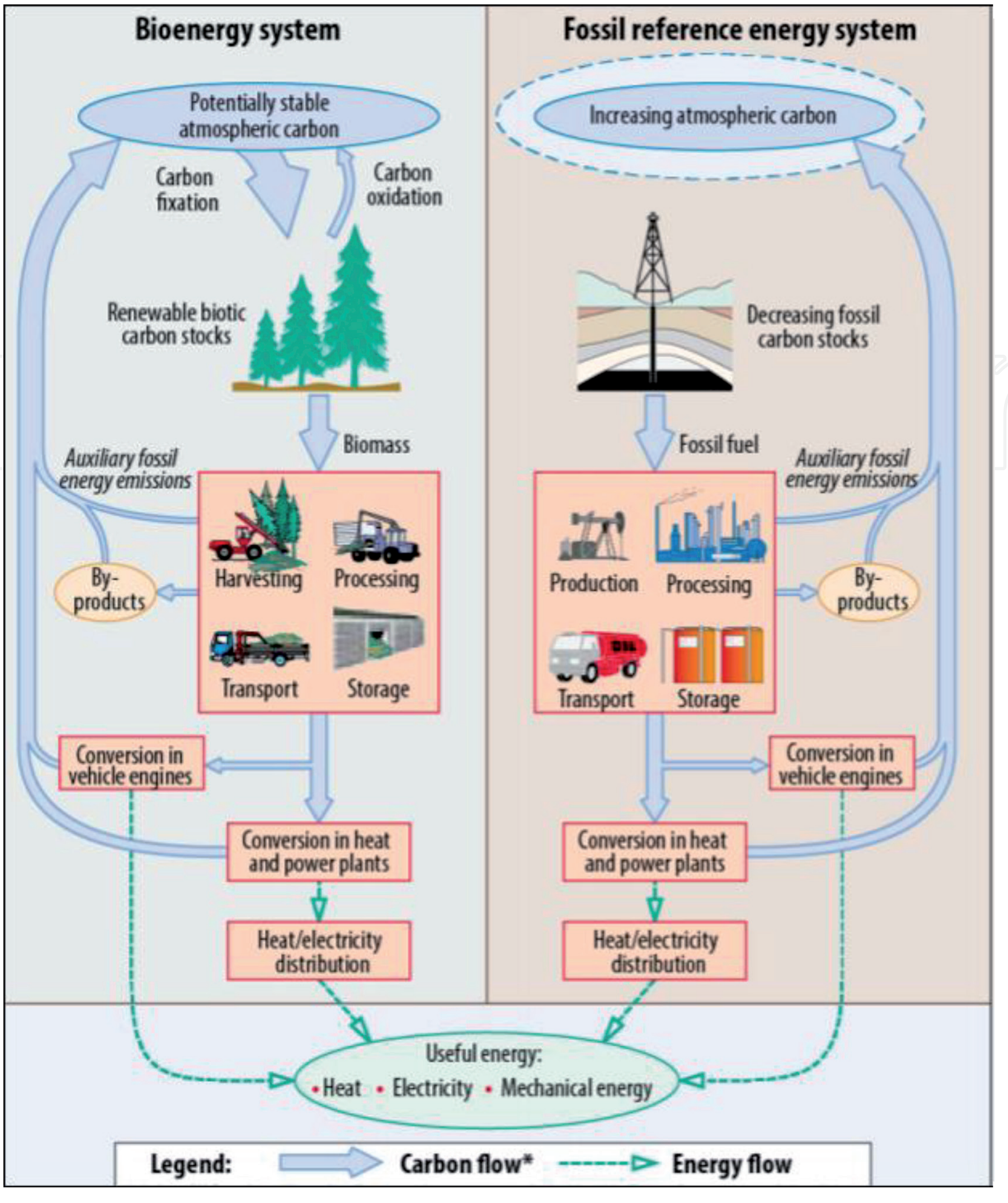

Figure 5.
Carbon cycles of bioenergy compared to fossil fuel sourced energy [43].

continue to absorb atmospheric CO_2. The resultant carbon reductions are included in the global estimates of CO_2 emissions in future and this in not precise since it results to double counting. Ritcher et al. [46] emphasized the computational error of carbon neutrality using the example of a hectare of cropped land that is left to reforest. In this case, the growing plants absorb atmospheric CO_2 to form biomass. Some of the biomass is eaten by microorganisms, fungi and animals and released to the atmosphere while the other is stored in soils and vegetation during growth processes. The overall effect would be reduced CO_2 emissions and a negative effect on global warming. On the other hand, if energy crops were cultivated to be combusted in power plants, fossil fuel based emissions would reduce but carbon emissions from the plants' chimneys would arise. Bird et al. [45] supported this line of thought claiming that for every unit of energy, CO_2 emitted from the power plants would even be higher that fossil fuels because (1) the efficiency of combusting biomass compared to fossil fuel is lower and (2) biomass has lower unit energy potential compared to natural gas or petroleum based power. Therefore growing energy crops draws CO_2 from the atmosphere but it foregoes the sequestration of this gas that would occur if the land was forested. The foregone CO_2 atmospheric withdrawals are not accounted in existent biomass GHG emission computation methods. The growth of forests in Ukrainian forests for instance after abandoning farmland resulted more carbon sinking at the rate of one ton per hectare of forested land annually [47]. The growth of energy crops causes more carbon to be sequestered in underground fossil fuels though the advantage has an opportunity cost of less carbon being stored in soils and plants. Biomass energy sources would reduce carbon emissions to be considered neutral if the former effect outweighs the latter.

The use of food crops such as maize, cassava, sorghum for energy crops is a perfect scenario to demystify the carbon neutrality debate. The process does not compensate the emissions from its use and does not directly lead to additional growth of plants [48, 49]. However, the energy crops can significantly reduce carbon emissions indirectly under the following circumstances:

1. The crops sequester carbon from the atmosphere for longer periods since humans and animals consume them and then return carbon during respiration. If the crops are not replaced, they result to net carbon reductions and their consumption emits less CO_2. However, the approach is not sustainable in reducing GHGs.

2. If more crops are concentrated per unit land, more carbon is absorbed. In the event more land is cultivated, carbon withdraws from the atmosphere are likely to increase.

In these two scenarios, carbon fluctuations due to land-use changes must be determined accurately. From the many considerations on biomass carbon neutrality made in this chapter, the main issue in the debate is the failure to consider the emissions that would result if bioenergy was produced from other alternatives apart from energy crops. This error results to incorrect GHG accounting [41]. Therefore, accurate GHG accounting should reflect the carbon stock losses during production of biomass, the energy consumed and consider the carbon withdrawals that would result if bioenergy was not used at all. In forested areas of countries at the northern hemisphere, biomass accumulation occurs [46, 50] resulting to more carbon sequestration. In events that the harvest of biomass does not surpass forest growth, carbon stocks are estimated to be constant and consequent GHG emission reductions can be realized [43, 51]. If forests are left to regrow following harvest, they realize the same carbon sequestration levels as the unharvested ones when carbon stock build up slows and stops at maturity. At that point, biomass use is considered carbon neutral. Such a realization could take many years and as such, atmospheric CO_2 is retained longer in the atmosphere before removal by plants, which is the cause of climate change [48, 49]. Increasing the harvest times for forests in the long term for sustainable fuel wood supply decreases the carbon stocks resulting to a carbon debt that is repaid after longer periods even if forest conservation occurs [51]. Holistic GHG emission accounting from biomass sources of energy should consider plant growth rate in the presence and absence of bioenergy generation and the changes in carbon storage in soils and plants as a result of the initiatives or otherwise.

6. Conclusions and recommendations

Biomass is a useful energy source in most African countries and is used for thermal applications in addition to cooking and producing electricity. As an alternative source of energy, it is essential as large part of the continent do not have direct access to electricity and other conventional energy sources. Additionally the use of fossil fuel based energy is associated with climate change among other environmental problems. Biomass is sourced from fuel wood, energy crops, municipal solid wastes and plant residues. This book chapter analyzed the technical and economic potential of biomass for energy in Africa based on literature. The findings showed that Africa has adequate land, climatic conditions, and a variety of suitable energy crops for biomass production. Evenly, the costs of biomass production though varied based on the country and climatic condition (humid, arid and semi-arid) are not as high. Biomass is therefore a potential driver to socio-economic growth of the continent through its capacity to enhance energy security. The chapter also explored on the carbon neutrality of biomass energy sources and laid the conditions for this realization. Additionally, the error in computing GHG emissions due to biomass production and use is discussed. Conclusively, biomass energy sources are renewable but not carbon neutral. This chapter therefore makes the following recommendations as efforts to realizing carbon neutrality through the use of biomass.

1. African countries and the rest of the world should formulate policies to encourage use of biomass for energy while reducing GHG emissions and not compromising ecosystems services of providing fiber and food.

2. Global expectations of bioenergy use potential and use should be modified to the earth's ability to produce more biomass without affecting natural ecosystems negatively.

3. Integrated biomass production that enhances food security should be encouraged through the preference to use biomass from residues, wastes and by-products unless needed in soil management for energy generation rather than fuel wood and food crops that have other competing needs.

4. Computation of GHGs resulting from biomass combustion should consider offsets from additional biomass cultivation, its reduced decomposition or otherwise in relation to CO_2 sequestration and release to the atmosphere.

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Conflict of interest

The authors declare no conflict of interest.

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